

## ULTRASONIC PULSE TRANSMISSION METHOD AND ULTRASONIC DIAGNOSTIC APPARATUS

### BACKGROUND OF THE INVENTION

5       The present invention relates to an ultrasonic pulse transmission method and an ultrasonic diagnostic apparatus, and more particularly to an ultrasonic pulse transmission method and an ultrasonic diagnostic apparatus that can prevent noticeable interleave blocks on a display screen.

      Japanese Patent Application Laid Open No. H3-126442 discloses an  
10   interleaving scanning technique involving, when a number of packets  $P$  ( $\geq 2$ ) is defined for conducting  $P$  ultrasonic pulse transmissions in one direction to acquire one acoustic line signal, interleaving an ultrasonic pulse transmission for acquiring a different acoustic line signal between the ultrasonic pulse transmissions in the one direction.

15       When the number of ultrasonic pulse transmissions in the different directions interleaved between the ultrasonic pulse transmissions in the one direction is defined as  $(I - 1)$ ,  $I$  is referred to as the number of interleaves.  $I$  is defined as  $I \geq 2$ .

      As an example, if the number of packets  $P = 2$ , the number of interleaves  $I =$   
20   3, and one frame is composed of acoustic lines lined up in a sequence of acoustic line 1, acoustic line 2, acoustic line 3, acoustic line 4, ..., then ultrasonic pulse transmissions are done in the following order:

      acoustic line 1 - acoustic line 2 - acoustic line 3 - acoustic line 1 - acoustic  
line 2 - acoustic line 3 - acoustic line 4 - acoustic line 5 - acoustic line 6 - acoustic  
25   line 4 - acoustic line 5 - acoustic line 6 - acoustic line 7 - acoustic line 8 - acoustic  
line 9 - acoustic line 7 - acoustic line 8 - acoustic line 9 -...

      In this example, interleaving is achieved by unitary acoustic line groups each comprised of the number of interleaves of adjacent acoustic lines, such as acoustic lines 1 - 3, acoustic lines 4 - 6, acoustic lines 7 - 9, and so forth.  
30   These acoustic line groups, each of which serves as a unit of interleaving, are

called interleave blocks.

Since the conventional interleaving scanning conducts interleaving within one frame, the one frame is constituted by concatenating a plurality of interleave blocks.

5        However, the difference in scan time between acoustic lines at a boundary of adjacent interleave blocks is larger than the difference in scan time between acoustic lines within an interleave block, which leads to a problem that difference in image quality occurs across interleave blocks, resulting in noticeable interleave blocks on an image.

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#### SUMMARY OF THE INVENTION

It is therefore an object to provide an ultrasonic pulse transmission method and an ultrasonic diagnostic apparatus that can prevent noticeable interleave blocks on a display screen.

15        In its first aspect, the present invention provides an ultrasonic pulse transmission method characterized in comprising: when a number of packets  $P$  ( $\geq 2$ ) is defined for conducting  $P$  ultrasonic pulse transmissions in one direction to acquire one acoustic line signal, interleaving at least one ultrasonic pulse transmission for acquiring an acoustic line signal that belongs to a frame different  
20        from that to which said former acoustic line signal belongs between the ultrasonic pulse transmissions in said one direction.

      The ultrasonic pulse transmission method of the first aspect conducts interleaving not within one frame but across a plurality of frames. Thus, a frame becomes free of interleave blocks, thereby preventing noticeable interleave  
25        blocks on a display screen.

      To implement the ultrasonic pulse transmission method, an ultrasonic diagnostic apparatus that can electronically or mechanically change the ultrasonic pulse transmission direction in two directions, one being a direction in which acoustic lines are lined up within one frame, the other being a direction in  
30        which two or more frames are laid.

In its second aspect, the present invention provides the ultrasonic pulse transmission method having the aforementioned configuration, characterized in comprising: when a number of interleaves  $I$  ( $\geq 2$ ) is defined, interleaving ultrasonic pulse transmissions for acquiring  $(I - 1)$  acoustic line signals that  
5 belong to  $(I - 1)$  frames different from the frame to which said former acoustic line signal belongs between the ultrasonic pulse transmissions in said one direction.

The ultrasonic pulse transmission method of the second aspect conducts interleaving not within one frame but across  $I$  frames. Thus, a frame becomes  
10 free of interleave blocks, thereby preventing noticeable interleave blocks on a display screen.

In its third aspect, the present invention provides an ultrasonic pulse transmission method characterized in comprising: when a number of packets  $P$  ( $\geq 2$ ) is defined for conducting  $P$  ultrasonic pulse transmissions in one direction  
15 to acquire one acoustic line signal, allowing selection between interleaving at least one ultrasonic pulse transmission for acquiring another acoustic line signal that belongs to the frame to which said former acoustic line signal belongs between the ultrasonic pulse transmissions in said one direction, and interleaving  
at least one ultrasonic pulse transmission for acquiring an acoustic line signal  
20 that belongs to a frame different from that to which said former acoustic line signal belongs between the ultrasonic pulse transmissions in said one direction.

According to the ultrasonic pulse transmission method of the third aspect, a mode in which interleaving is achieved within one frame or a mode in which interleaving is achieved across a plurality of frames can be selected. Thus, an  
25 appropriate mode can be selected according to an application of interleaving scanning.

In its fourth aspect, the present invention provides the ultrasonic pulse transmission method having the aforementioned configuration, characterized in comprising: when a number of interleaves  $I$  ( $\geq 2$ ) is defined, interleaving  
30 ultrasonic pulse transmissions for acquiring  $(I - 1)$  other acoustic line signals that

belong to the frame to which said former acoustic line signal belongs between the ultrasonic pulse transmissions in said one direction, or interleaving ultrasonic pulse transmissions for acquiring  $(I - 1)$  acoustic line signals that belong to  $(I - 1)$  frames different from the frame to which said former acoustic line signal belongs  
5 between the ultrasonic pulse transmissions in said one direction.

According to the ultrasonic pulse transmission method of the fourth aspect, a mode in which interleaving is achieved by a unit of  $I$  acoustic lines within one frame or a mode in which interleaving is achieved across  $I$  frames can be selected. Thus, an appropriate mode can be selected according to an application of  
10 interleaving scanning.

In its fifth aspect, the present invention provides the ultrasonic pulse transmission method having the aforementioned configuration, characterized in comprising: electronically changing the ultrasonic pulse transmission direction among acoustic line signals that belong to the same frame, and also electronically  
15 changing the ultrasonic pulse transmission direction among acoustic line signals that belong to different frames.

According to the ultrasonic pulse transmission method of the fifth aspect, an ultrasonic probe that can electronically change the ultrasonic pulse transmission direction in two directions, one being a direction in which acoustic  
20 lines line up within one frame, the other being a direction in which two or more frames are laid, can be used.

In its sixth aspect, the present invention provides the ultrasonic pulse transmission method having the aforementioned configuration, characterized in comprising: electronically changing the ultrasonic pulse transmission direction  
25 among acoustic line signals that belong to the same frame, and mechanically changing the ultrasonic pulse transmission direction among acoustic line signals that belong to different frames.

According to the ultrasonic pulse transmission method of the sixth aspect, an ultrasonic probe that can electronically change the ultrasonic pulse  
30 transmission direction in a direction in which acoustic lines line up within one

frame, and mechanically change the ultrasonic pulse transmission direction in a direction in which two or more frames are laid, can be used.

In its seventh aspect, the present invention provides the ultrasonic pulse transmission method having the aforementioned configuration, characterized in comprising: conducting ultrasonic pulse transmissions simultaneously in  
5 different directions to simultaneously acquire a plurality of acoustic line signals.

According to the ultrasonic pulse transmission method of the seventh aspect, an ultrasonic probe that can transmit ultrasonic pulses simultaneously in two or more transmission directions can be used.

10 In its eighth aspect, the present invention provides the ultrasonic pulse transmission method having the aforementioned configuration, characterized in comprising: acquiring acoustic line signals containing flow information.

The ultrasonic pulse transmission method of the eighth aspect can prevent noticeable interleave blocks on a display screen in collecting three-dimensional  
15 data by a CF (color flow) or B-flow technique.

In its ninth aspect, the present invention provides an ultrasonic diagnostic apparatus characterized in comprising: an ultrasonic probe; number-of-frames defining means for defining a number of frames  $f$ ; number-of-packets defining means for defining a number of packets  $P$  ( $\geq 2$ ); transmitting/receiving means for  
20 driving said ultrasonic probe to conduct  $P$  ultrasonic pulse transmissions in one direction and receive echoes to acquire an acoustic line signal; and transmission direction control means for controlling the transmission direction to interleave at least one ultrasonic pulse transmission for acquiring an acoustic line signal that belongs to a frame different from that to which said former acoustic line signal  
25 belongs between the ultrasonic pulse transmissions in said one direction.

The ultrasonic diagnostic apparatus of the ninth aspect can suitably implement the ultrasonic pulse transmission method of the first aspect.

In its tenth aspect, the present invention provides the ultrasonic diagnostic apparatus having the aforementioned configuration, characterized in that: said  
30 apparatus comprises number-of-interleaves defining means for defining a

number of interleaves  $I (\geq 2)$ ; and said transmission direction control means controls the transmission direction to interleave ultrasonic pulse transmissions for acquiring  $(I - 1)$  acoustic line signals that belong to  $(I - 1)$  frames different from the frame to which said former acoustic line signal belongs between the  
5 ultrasonic pulse transmissions in said one direction.

The ultrasonic diagnostic apparatus of the tenth aspect can suitably implement the ultrasonic pulse transmission method of the second aspect.

In its eleventh aspect, the present invention provides an ultrasonic diagnostic apparatus characterized in comprising: an ultrasonic probe;  
10 number-of-frames defining means for defining a number of frames  $f$ ;  
number-of-packets defining means for defining a number of packets  $P (\geq 2)$ ;  
transmitting/receiving means for driving said ultrasonic probe to conduct  $P$  ultrasonic pulse transmissions in one direction and receive echoes to acquire an acoustic line signal; transmission direction control means for controlling the  
15 transmission direction in an intra-frame mode in which the transmission direction is controlled to interleave at least one ultrasonic pulse transmission for acquiring another acoustic line signal that belongs to the frame to which said former acoustic line signal belongs between the ultrasonic pulse transmissions in said one direction, or in an inter-frame mode in which the transmission direction  
20 is controlled to interleave at least one ultrasonic pulse transmission for acquiring an acoustic line signal that belongs to a frame different from that to which said former acoustic line signal belongs between the ultrasonic pulse transmissions in said one direction; and interleave mode selecting means for an operator to select between said intra-frame mode and inter-frame mode.

25 The ultrasonic diagnostic apparatus of the eleventh aspect can suitably implement the ultrasonic pulse transmission method of the third aspect.

In its twelfth aspect, the present invention provides the ultrasonic diagnostic apparatus having the aforementioned configuration, characterized in that: said apparatus comprises number-of-interleaves defining means for  
30 defining a number of interleaves  $I (\geq 2)$ ; and said transmission direction control

means controls the transmission direction to interleave ultrasonic pulse transmissions for acquiring (I - 1) other acoustic line signals that belong to the frame to which said former acoustic line signal belongs between the ultrasonic pulse transmissions in said one direction, or to interleave ultrasonic pulse transmissions for acquiring (I - 1) acoustic line signals that belong to (I - 1) frames different from the frame to which said former acoustic line signal belongs between the ultrasonic pulse transmissions in said one direction.

The ultrasonic diagnostic apparatus of the twelfth aspect can suitably implement the ultrasonic pulse transmission method of the fourth aspect.

10 In its thirteenth aspect, the present invention provides the ultrasonic diagnostic apparatus having the aforementioned configuration, characterized in that: said ultrasonic probe is a two-dimensional array ultrasonic probe; and said transmission direction control means electronically changes the ultrasonic pulse transmission direction among acoustic line signals that belong to the same frame, and also electronically changes the ultrasonic pulse transmission direction among acoustic line signals that belong to different frames.

The ultrasonic diagnostic apparatus of the thirteenth aspect can suitably implement the ultrasonic pulse transmission method of the fifth aspect.

20 In its fourteenth aspect, the present invention provides the ultrasonic diagnostic apparatus having the aforementioned configuration, characterized in that: said apparatus comprises a mechanism that can mechanically change orientation of said ultrasonic probe in a direction orthogonal to a frame; and said transmission direction control means electronically changes the ultrasonic pulse transmission direction among acoustic line signals that belong to the same frame, and mechanically changes the ultrasonic pulse transmission direction among acoustic line signals that belong to different frames.

The ultrasonic diagnostic apparatus of the fourteenth aspect can suitably implement the ultrasonic pulse transmission method of the sixth aspect.

30 In its fifteenth aspect, the present invention provides the ultrasonic diagnostic apparatus having the aforementioned configuration, characterized in

that: said transmitting/receiving means conducts ultrasonic pulse transmissions simultaneously in different directions to simultaneously acquire a plurality of acoustic line signals.

The ultrasonic diagnostic apparatus of the fifteenth aspect can suitably  
5 implement the ultrasonic pulse transmission method of the seventh aspect.

In its sixteenth aspect, the present invention provides the ultrasonic diagnostic apparatus having the aforementioned configuration, characterized in that: said transmitting/receiving means acquires acoustic line signals containing flow information.

10 The ultrasonic diagnostic apparatus of the sixteenth aspect can suitably implement the ultrasonic pulse transmission method of the eighth aspect.

According to the ultrasonic pulse transmission method and ultrasonic diagnostic apparatus of the present invention, when collecting three-dimensional data by a CF or B-flow technique in real-time, for example, and producing a  
15 projection image for display, noticeable interleave blocks on a display screen can be prevented.

Further objects and advantages of the present invention will be apparent from the following description of the preferred embodiments of the invention as illustrated in the accompanying drawings.

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#### BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a configuration diagram showing an ultrasonic diagnostic apparatus in accordance with one embodiment of the present invention.

Figure 2 is a flow chart showing interleaved transmission processing in  
25 accordance with one embodiment of the present invention.

Figure 3 is an explanatory diagram showing intra-frame mode interleaving.

Figure 4 is an explanatory diagram showing inter-frame mode interleaving.

Figure 5 is an explanatory diagram showing a case in which the inter-frame mode is applied when transmission is conducted simultaneously in two  
30 transmission directions.



Figure 6 is an explanatory diagram showing a case in which the inter-frame mode is applied when reception is conducted with four reception directions corresponding to one transmission direction.

Figure 7 is an explanatory diagram showing a case in which the inter-frame mode is applied when reception is conducted with nine reception directions corresponding to one transmission direction.

#### DETAILED DESCRIPTION OF THE INVENTION

The present invention will now be described in more detail with reference to embodiments shown in the accompanying drawings.

Figure 1 is a configuration diagram of an ultrasonic diagnostic apparatus 100 in accordance with one embodiment of the present invention.

The ultrasonic diagnostic apparatus 100 comprises an ultrasonic probe 1, a transmitting/receiving section 2 for driving the ultrasonic probe 1 to transmit ultrasonic pulses in a desired transmission direction and receive echoes and outputting received data, a signal processing section 3 for producing an ultrasonic image from the received data, an image display section 4 for displaying the image, a data storing section 5 for storing the image and three-dimensional data, a control section 6 for controlling the overall operation, and an operating section 7 for an operator to define the number of packets P and the like, and supply instructions.

The control section 6 comprises a number-of-frames defining section 6a for defining a number of frames based on instructions by the operator, a number-of-packets defining section 6b for defining a number of packets P based on instructions by the operator, a number-of-interleaves defining section 6c for defining a number of interleaves I based on instructions by the operator, an interleave mode selecting section 6d for selecting an interleave mode from between an intra-frame mode and an inter-frame mode based on instructions by the operator, and a transmission direction control section 6e for controlling the ultrasonic pulse transmission direction based on the defined conditions.

The ultrasonic probe 1 is a two-dimensional array ultrasonic probe that electronically changes the ultrasonic pulse transmission direction among acoustic line signals that belong to the same frame, and also electronically changes the ultrasonic pulse transmission direction among acoustic line signals that belong to  
5 different frames.

The ultrasonic probe may be one that mechanically changes the ultrasonic pulse transmission direction among acoustic line signals that belong to different frames.

Figure 2 is a flow chart showing interleaved transmission processing by the  
10 ultrasonic diagnostic apparatus 100.

At Step S1, the number-of-frames defining section 6a defines a number of frames. Here, it is assumed that a number of frames = 3 is defined. In this case, three-dimensional data will be collected by scanning three frames: first frame F1, second frame F2, and third frame F3, as shown in Figure 1.

15 At Step S2, the number-of-packets defining section 6b defines a number of packets P. Here, it is assumed that a number of packets  $P = 4$  is defined. In this case, one acoustic line signal will be acquired by conducting four ultrasonic pulse transmissions in one transmission direction, as shown in Figures 3 and 4.

At Step S3, the number-of-interleaves defining section 6c defines a number  
20 of interleaves I. Here, it is assumed that a number of interleaves  $I = 3$  is defined. In this case, each ultrasonic pulse transmission in one transmission direction is interleaved with ultrasonic pulse transmissions in two other transmission directions, as shown in Figures 3 and 4.

At Step S4, the interleave mode selecting section 6d prompts the operator  
25 to select an interleave mode.

Alternatively, a configuration may be adopted such that when a projection image of three-dimensional data is produced and displayed in real-time, for example, the interleave mode selecting section 6d automatically selects a mode according to the projection direction, e.g., selects an inter-frame mode if the angle  
30 between a projection direction and the frame is 45 degrees or more, and selects

an intra-frame mode if the angle between the projection direction and a frame is less than 45 degrees.

At Step S5, if the intra-frame mode is selected, the flow proceeds to Step S6, and if the inter-frame mode is selected, the flow proceeds to Step S7.

5 At Step S6, an intra-frame interleaving scan is conducted. The intra-frame interleaving scan will be described later with reference to Figure 3.

At Step S7, an inter-frame interleaving scan is conducted. The inter-frame interleaving scan will be described later with reference to Figures 4 – 7.

By conducting the interleaving scan at Step S6 or S7, three-dimensional CF  
10 (color flow) or B-flow data are collected in real-time, and a projection image is produced from the three-dimensional data for display.

Figure 3 is an explanatory diagram of an intra-frame interleaving scan.

Assuming that the number of packets  $P = 4$ , the number of interleaves  $I = 3$ , a first frame F1 is composed of sequentially lined-up acoustic lines S11 – S16, a  
15 second frame F2 is composed of sequentially lined-up acoustic lines S21 – S26, and a third frame F3 is composed of sequentially lined-up acoustic lines S31 – S36, then ultrasonic pulse transmissions are conducted by cyclically repeating the process below. The numbers in parentheses are indices indicating the order of transmission.

20 (0) S11 - (1) S12 - (2) S13 - (3) S11 - (4) S12 - (5) S13 - (6) S11 - (7) S12 - (8) S13 - (9) S11 - (10) S12 - (11) S13 - (12) S14 - (13) S15 - (14) S16 - ... - (21) S14 - (22) S15 - (23) S16 - (24) S21 - (25) S22 - (26) S23 - (27) S21 - (28) S22 - (29) S23 - ... - (45) S24 - (46) S25 - (47) S26 - (48) S31 - (49) S32 - (50) S33 - ... - (69) S34 - (70) S35 - (71) S36.

In the process of Figure 3, the acoustic lines S11 – S13 in the first frame F1,  
25 the acoustic lines S14 – S16 in the first frame F1, the acoustic lines S21 – S23 in the second frame F2, the acoustic lines S24 – S26 in the second frame F2, the acoustic lines S31 – S33 in the third frame F3, and the acoustic lines S34 – S36 in the third frame F3 constitute respective interleave blocks. Thus, when a projection image in a projection direction orthogonal to a frame is observed, for  
30 example, the interleave blocks are sometimes noticeable on an image.

Accordingly, the interleave mode may be changed to an inter-frame mode in such a case.

Figure 4 is an explanatory diagram of an inter-frame interleaving scan.

Assuming that the number of packets  $P = 4$ , the number of interleaves  $I = 3$ ,  
 5 a first frame F1 is composed of sequentially lined-up acoustic lines S11 – S16, a second frame F2 is composed of sequentially lined-up acoustic lines S21 – S26, and a third frame F3 is composed of sequentially lined-up acoustic lines S31 – S36, then ultrasonic pulse transmissions are conducted by cyclically repeating the process below. The numbers in parentheses are indices indicating the order of  
 10 transmission.

(0) S11 - (1) S21 - (2) S31 - (3) S11 - (4) S21 - (5) S31 - (6) S11 - (7) S21 - (8) S31  
 - (9) S11 - (10) S21 - (11) S31 - (12) S12 - (13) S22 - (14) S32 - ... - (69) S16 - (70) S26 -  
 (71) S36.

In the process of Figure 4, no interleave block is formed in the frames F1, F2  
 15 and F3. Thus, when a projection image in a projection direction orthogonal to a frame is observed, for example, the interleave blocks are never noticeable on an image.

Figure 5 shows a case in which the inter-frame mode is applied to a multi-beam technique for transmitting ultrasonic pulses simultaneously in  
 20 different transmission directions.

The equally numbered indices in the transmission sequence in Figure 5 represent simultaneous ultrasonic pulse transmissions.

By using the multiple beams, the frame rate can be improved.

Figure 6 shows a case in which the inter-frame mode is applied when an  
 25 ultrasonic pulse is transmitted in one transmission direction and acoustic line signals in four reception directions (each enclosed by a dot-dash line box) corresponding to the transmission direction are simultaneously acquired.

S12\_1, S12\_2, S12\_3,... represent transmission positions (x-z positions), R11, R12, R13,... represent reception positions (x-z positions), and F1, F2,... represent  
 30 frame positions (x-z positions).

By focusing on transmission directions S12\_1, S12\_2, S12\_3, ... , S56\_3, it can be seen that the transmission sequence is equivalent to that of Figure 4.

Figure 7 shows a case in which the inter-frame mode is applied when an ultrasonic pulse is transmitted in one transmission direction and acoustic line  
5 signals in nine reception directions (each enclosed by a dot-dash line box) corresponding to the transmission direction are simultaneously acquired.

S123\_1, S123\_2, S123\_3,... represent transmission positions (x-z positions), R11, R12, R13,... represent reception positions (x-z positions), and F1, F2,... represent frame positions (x-z positions).

10 By focusing on transmission directions S123\_1, S123\_2, S123\_3, ... , S789\_3, it can be seen that the transmission sequence is equivalent to that of Figure 4.

Many widely different embodiments of the invention may be configured without departing from the spirit and the scope of the present invention. It should be understood that the present invention is not limited to the specific  
15 embodiments described in the specification, except as defined in the appended claims.